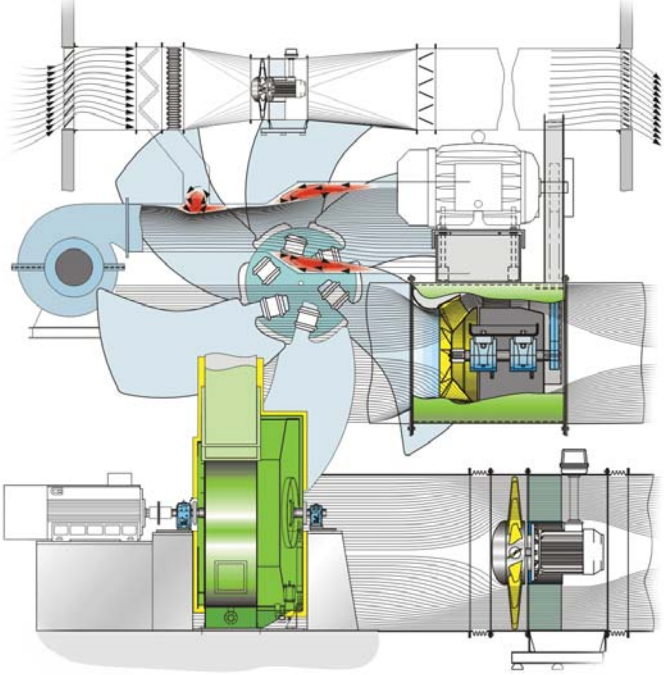

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Good Practice Guide

Energy savings in fans and fan systems

ACTIONenergy

From the Carbon Trust

Contents

1 Introduction

This guide introduces the energy efficiency fundamentals of fans and fan systems, and describes the concepts and factors that will help companies understand the requirements for buying, designing, installing, operating and maintaining energy efficient equipment.

The guide is aimed at people who operate, maintain or are otherwise responsible for process installations that use fans to move air or other gases. It is intended to help them understand how to save energy in the operation of existing installations and how to minimise energy use when selecting fans for new or refurbished installations. The guide assumes little prior knowledge of fan engineering and includes a glossary of relevant technical terms (see Appendix A).

1.1 Fan energy consumption and potential savings[1]

It is estimated that, in the UK, fans use some 28,500GWh/year of energy at an annual cost of £72 billion. The potential for energy savings is 20–25% (5,700GWh/year–7,125GWh/year, equivalent to £14.4–18 billion/year). Two-thirds of these potential energy savings are from system improvements and one-third from the fans themselves.

The potential reduction in carbon dioxide emissions associated with these energy savings from fans (all types) is 3.2 million tonnes/year.

Thus, there is considerable scope for improving the energy efficiency of fans and fan systems. As well as reducing energy costs, this usually has the added benefit of increasing reliability and hence reducing service and downtime costs throughout the life of plant.

1.2 The purpose of the guide

The information in this guide will help those who own, design or service fan systems to understand the key energy saving technologies and thus maximise their energy and carbon savings.

To achieve energy savings, designers and engineers need to understand the various elements and operation of fans and fan systems. Section 2 describes the basic principles of fans and fan systems, and introduces the concept of fan characteristics and the fan laws.

Section 3 takes a more detailed look at how fans are designed and how to select the most appropriate system for a particular application. It includes a comprehensive summary table, with information about the efficiency, performance characteristics and typical applications of 16 different types of fan. Two examples of fan applications (in coal-fired power generation and for dust/fume extraction) are considered in Section 4.

Section 5 contains a comprehensive energy saving checklist to help readers identify potential improvements in fan efficiency and thus achieve energy and carbon savings.

Appendix A contains a glossary of terms used in the guide. Appendix B describes how to calculate the life-cycle cost of a fan installation: over its life, the cost of energy used will be considerably more than the initial capital cost. Installation of the most efficient fan and motor will therefore lead to significant cost savings over the operating life of the system. Appendix C gives details of useful contacts for further information and possible reference sources.

1 Data taken from: Market Study for Improving Energy Efficiency for Fans. Peter Radgen (editor). ISBN 3816761372. Fraunhofer IRB Verlag (2002)

2 Basic principles of fans and fan systems

In order to reduce energy use by fans and fan systems, it is necessary to have a basic understanding of how fans and fan systems work. This section describes:

- The purpose of a fan
- The main components of a fan and how they function
- The different types of fan and how they operate
- The terminology used to describe the pressure produced by a fan in an air moving system
- The meaning of fan characteristics, the fan laws and system resistance laws.

2.1 What is a fan and a fan system?

A fan is a machine with a rotating shaft on which impellers or blades are mounted. These exert force on the surrounding air or gas and result in a continuous flow at raised pressure, without changing density.

The prime function of a fan is to move relatively large volumes of air or gas at pressures that are sufficient to overcome the resistance of the systems to which they are attached. A fan's aerodynamic performance in terms of the pressure it generates is a function of flow rate, and its efficiency differentiates one fan type from another.

A fan system may consist simply of a fan with ducting connected to either the inlet or the outlet, or to both. A more complicated system could include a fan, ductwork, air control dampers, heat exchanger, filter, diffuser and noise attenuator (see Figure 1). The fan is the component that provides energy to the air stream to overcome the resistance to flow due to the other system components.

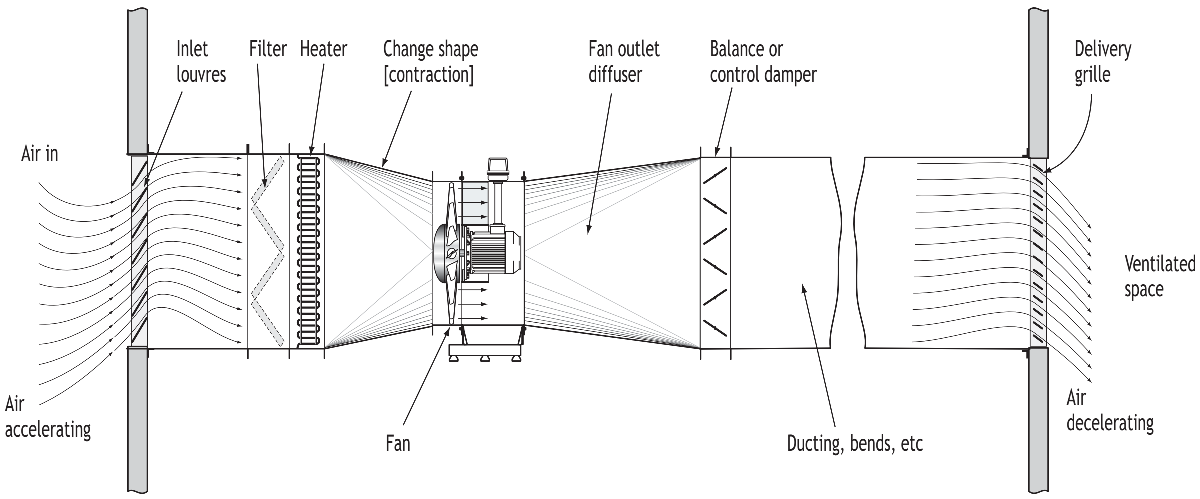


Figure 1 *A fan within a fan system*

2.2 Fan components

A fan has three main components (see Figure 2):

- The impeller (sometimes called the wheel or rotor)
- The means of driving the impeller (normally an electric motor)
- The casing (e.g. inlet flare, static hub fairings, impeller housing, fan casing and motor supports).

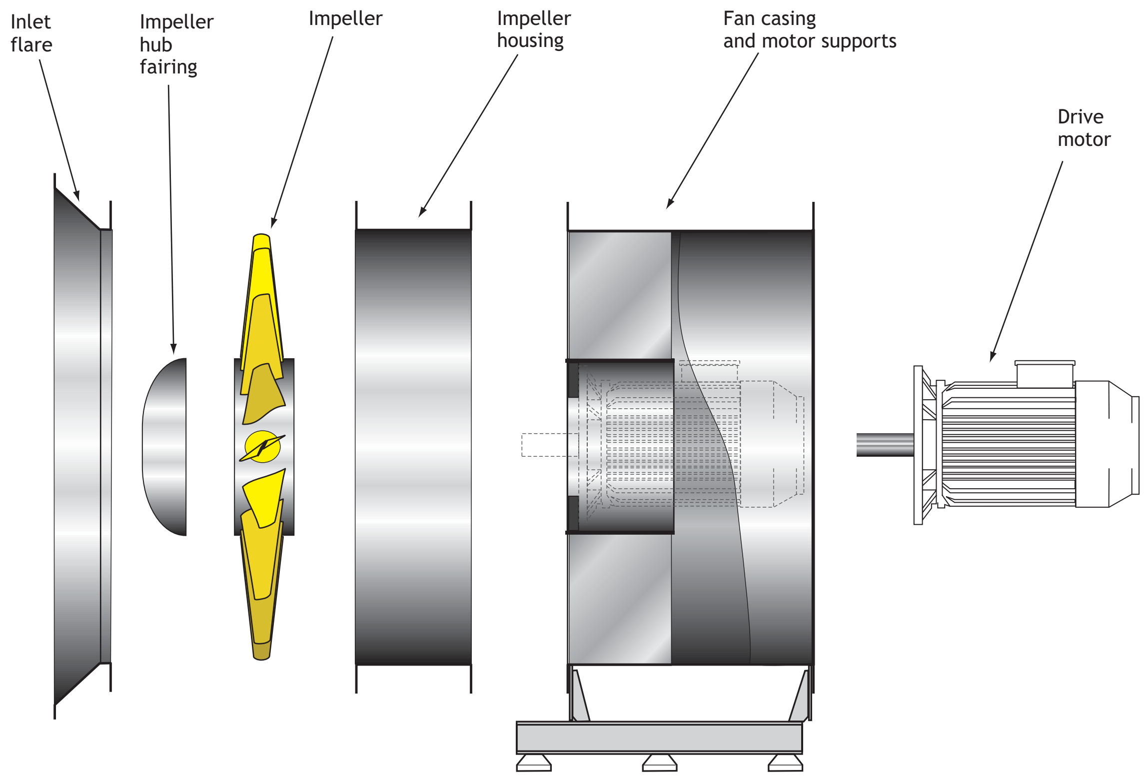


Figure 2 Main components of an axial flow fan

2.2.1 The impeller

Energy is transferred to the surrounding air or gas by rotation of the impeller. To cover a wide range of applications, fan impellers are made in a variety of types. These can be divided into four categories according to the path taken by the air through the impeller and the resulting mechanism of pressure generation:

- Centrifugal (see Figure 3)
- Axial (see Figure 4)
- Mixed flow (see Figure 5)
- Cross flow (see Figure 6).

Table 2 (see Section 3.2) gives examples of the many types of fan and their applications.

In the centrifugal type, the centrifugal force generated by the mass of air contained within the impeller, as well as the force exerted by the angle of the blades to the incoming air, generates both static and velocity pressure (see Section 2.3). These forces move the air through the system.

In the axial or propeller type, there is little or no centrifugal action, but the blades are set at an angle relative to the direction of air entry and so generate a lift or pressure difference.

In mixed flow and cross flow types, energy is imparted to the air in a combination of these ways.

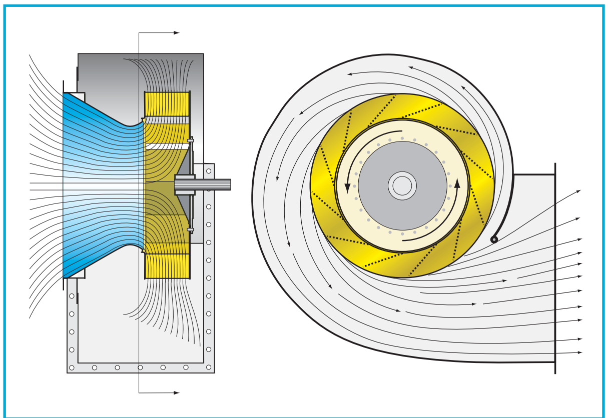


Figure 3 *Centrifugal fan*

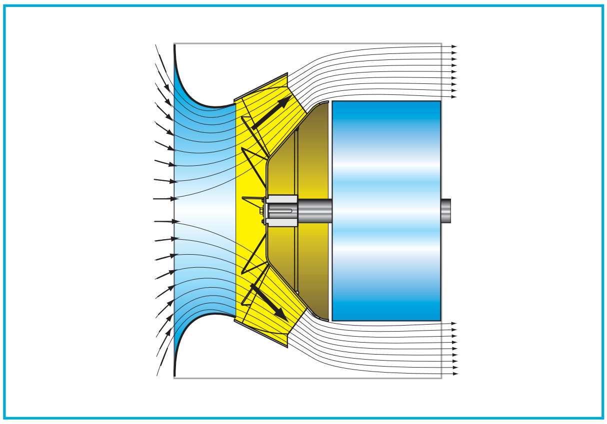


Figure 5 *Mixed flow fan*

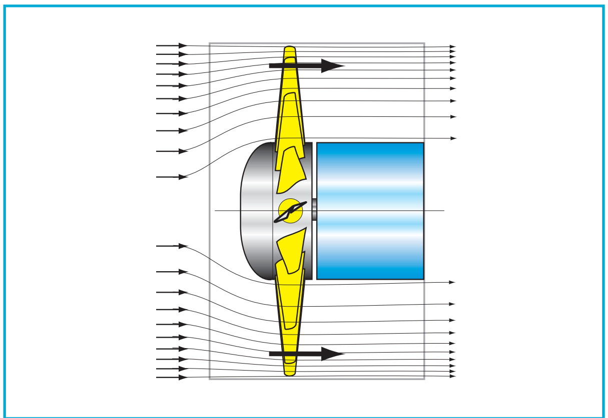


Figure 4 *Axial fan*

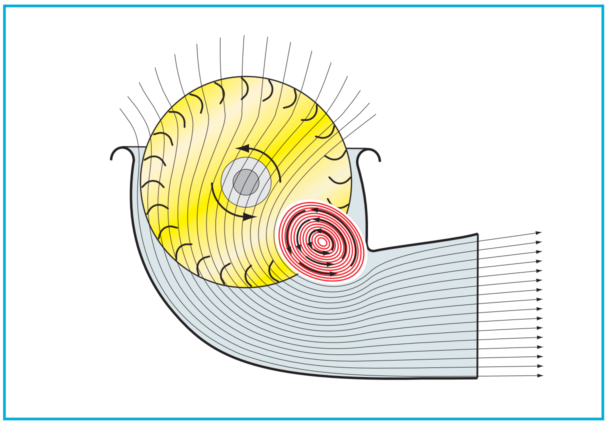


Figure 6 *Cross flow fan (view onto impeller)*

2.2.2 The casing

The casing (see Figure 7) should not be regarded as just an enclosure for the impeller to channel the air in a certain direction. The casing plays an important part in the aerodynamic performance (particularly in the case of centrifugal, cross flow and mixed flow fans, where it is a major element that converts velocity energy to useful static pressure). In axial fans, the impeller tip clearance is important for aerodynamic performance.

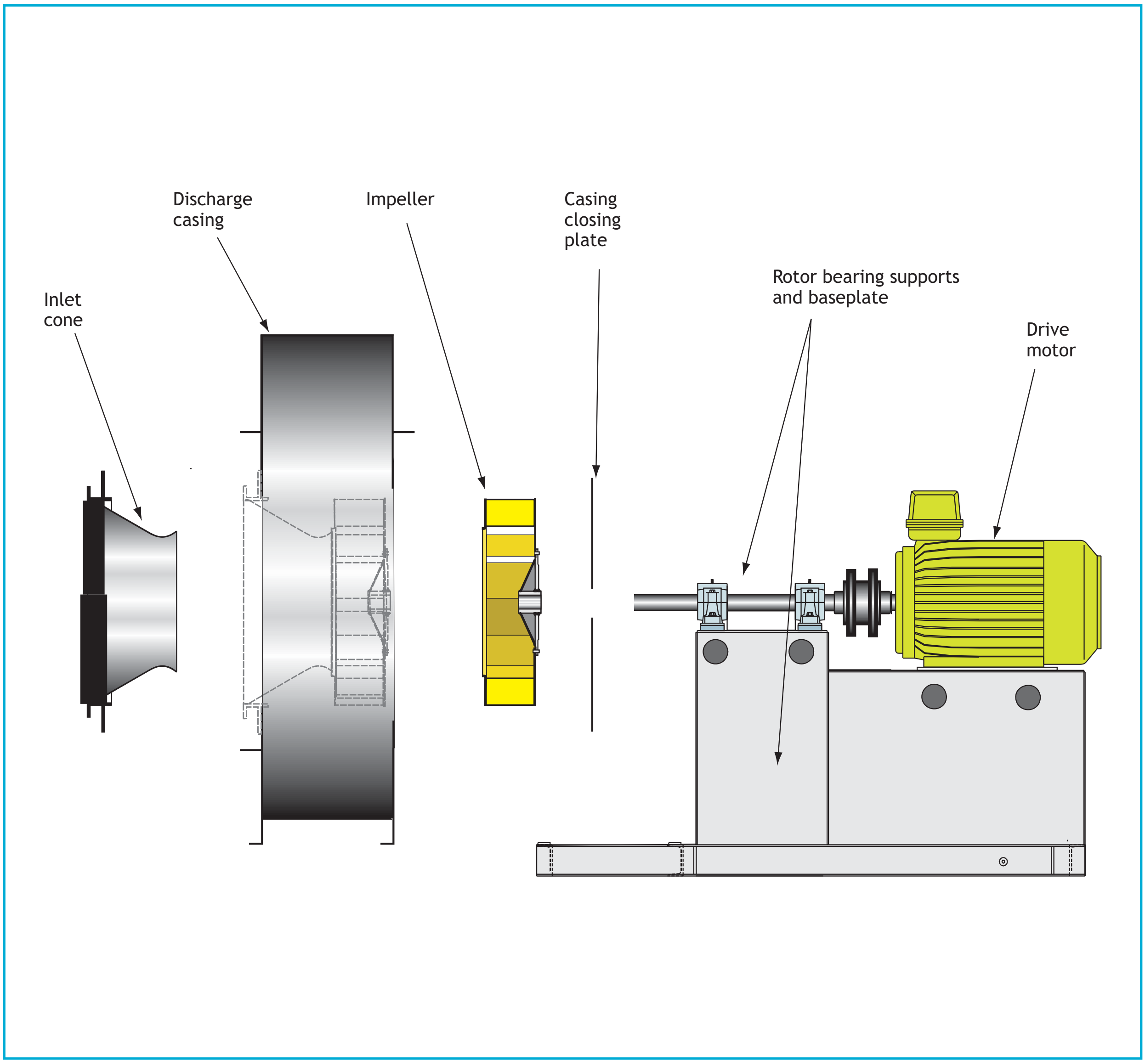


Figure 7 *Diagram of a centrifugal fan showing the casing*

2.3 Static, velocity and total pressure

Atmospheric air experiences a pressure caused by the weight of the air above. This is the barometric pressure (p_0) and is quite substantial, being typically 100 kilopascals (kPa).

If air is blown into a balloon, it can be described as being 'under pressure'; the 'skin' of the balloon applies the pressure. The air inside the balloon experiences a greater pressure than the atmospheric air outside, though the difference will be relatively small, e.g. 105kPa compared with 100kPa in the atmosphere.

The term 'pressure' describes both that inside and outside the balloon, assuming the air to be still in both cases. The term absolute pressure is used for clarity; thus, in the example the absolute pressure inside the balloon is 105kPa, and outside the balloon it is 100kPa.

2.3.1 Static pressure (p_s)

The difference between the absolute pressure at the point under consideration and the atmospheric pressure is what is important in fan engineering. This is termed the static pressure and corresponds to the potential energy of the air stream. In the example of the balloon above, the static pressure is 5kPa (105 – 100). Static pressure is shown as positive when the absolute pressure is greater than atmospheric pressure, and negative when it is below atmospheric pressure.

Static pressure can also be described as the pressure exerted against the side of the duct measured at right angles to the direction of flow.

Working with static pressures rather than absolute pressures compensates for natural variations in atmospheric pressure. For example, if the barometric pressure had been 96kPa, then blowing up the balloon to 101kPa would have required the same effort and produced the same static pressure in the balloon as before (5kPa).

Calculations in terms of static pressure can only be independent of atmospheric pressure if the static pressure is relatively small compared with atmospheric pressure. Air can then be treated as an incompressible fluid.

2.3.2 Velocity pressure (p_v)

Velocity pressure is an important quantity to which all the pressure and drag effects of a moving air stream can be related. What counts is the velocity of the body relative to the undisturbed air. Velocity pressure corresponds to the kinetic energy of the air stream.

$p_v = \frac{1}{2} \rho_v^2$ where ρ = density of air or gas and
v = velocity of air or gas

The movement of air or gas exerts a force on an object in its path. This is mainly because the pressure on the windward side is greater than that on the leeward side. The air or gas is not stopped by the object, but flows round it. The air is brought to rest at one point on the surface of the object.

2.3.3 Total pressure (p_t)

The sum of the static pressure and the velocity pressure at any point in the air is called the total pressure.

$$p_t = p_s + p_v = p_s + \frac{1}{2} \rho_v^2$$

To raise the pressure of the air or gas, work must be done on it, i.e. the air or gas must absorb energy. In the example above, we need to use our lungs or a balloon pump to increase the pressure in the balloon. Conversely, if the pressure falls, the air or gas must give out energy.

In the example with the balloon, the air is not moving and therefore there is no velocity pressure component to take into account. The static pressure therefore equals the total pressure.

2.4 Fan types

Different designs are possible within each of the four categories of impeller. Figure 8 provides examples of the relative volume flow, pressure and size of each category at equal power output.

Table 2 (see Section 3.2) gives details of the impeller design, efficiency, performance characteristics and typical applications for the main types of fan.

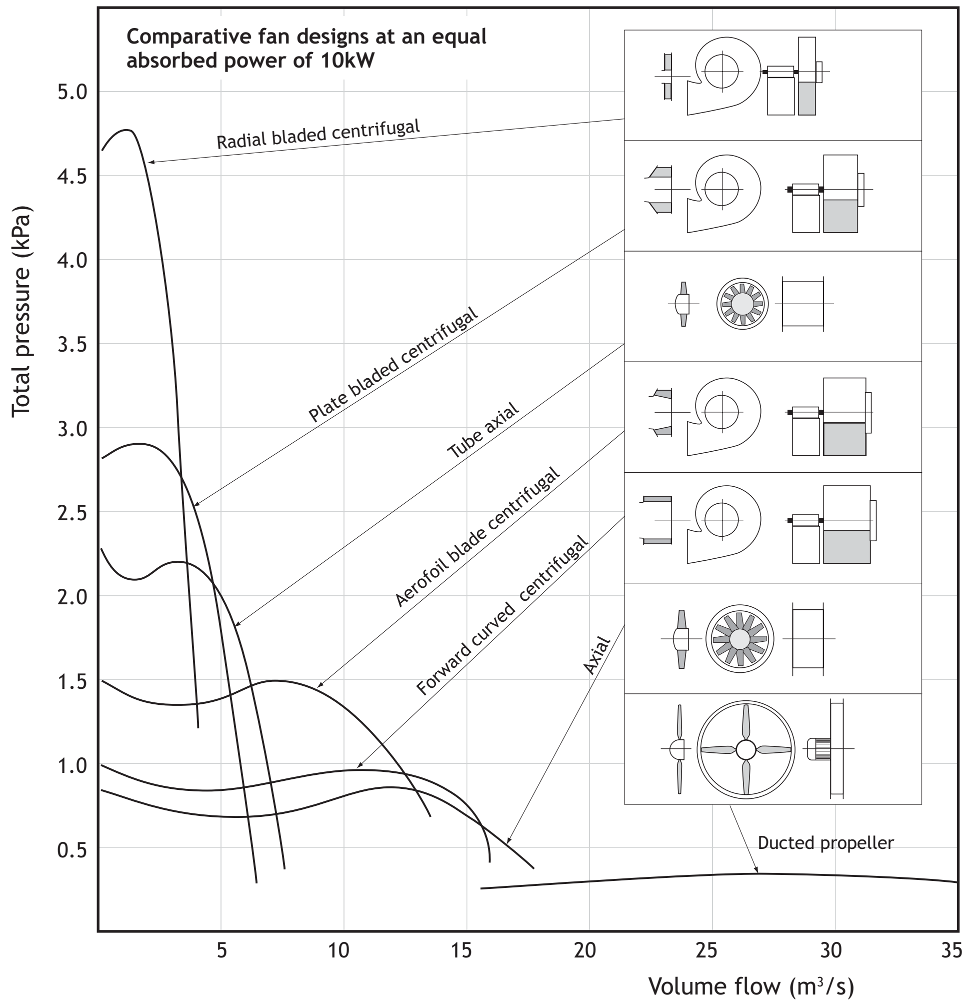


Figure 8 *Comparison of fan designs at equal power output* *(Courtesy of Fläkt Woods Ltd)*

2.5 Fan characteristics

Fan performance is described in terms of pressure and volume flow. However, it cannot be described adequately by single values of pressure rise or volume flow. Both qualities are flexible, but they have a fixed relationship with one another. This relationship is best defined graphically in the form of a fan characteristic (Figure 9 is an example); the volume flow rate is always plotted along the x-axis and with the fan total pressure (and other performance quantities) along the y-axis.

One point on the characteristic can always be found at which the efficiency of the fan is at a maximum – this is called the peak efficiency point (**A** in Figure 9). As well as providing the lowest consumption for a given duty, operation at this point usually secures the lowest noise level for a particular fan.

For maximum efficiency and energy savings, the fan selected should operate as closely as possible to the peak efficiency point.

In the real world, the fan can be operated successfully at other points on the characteristic. Where the fan and system curves intersect is the actual duty point at which the fan operates (this is shown by the **Design duty** point in Figure 9). The fan manufacturer should give a guaranteed performance range, which defines the region of satisfactory operation (such a range is indicated in Figure 9 by the heavy line part of the characteristic). Outside this range, the fan efficiency is lower and is likely to be unacceptable in terms of performance, noise or cost. The fan manufacturer may not recommend part of the characteristic because operation in that region could cause unsteady flow or vibration. For axial fans, where the motor is in the air stream, it may also result in undercooling of the electric motor.

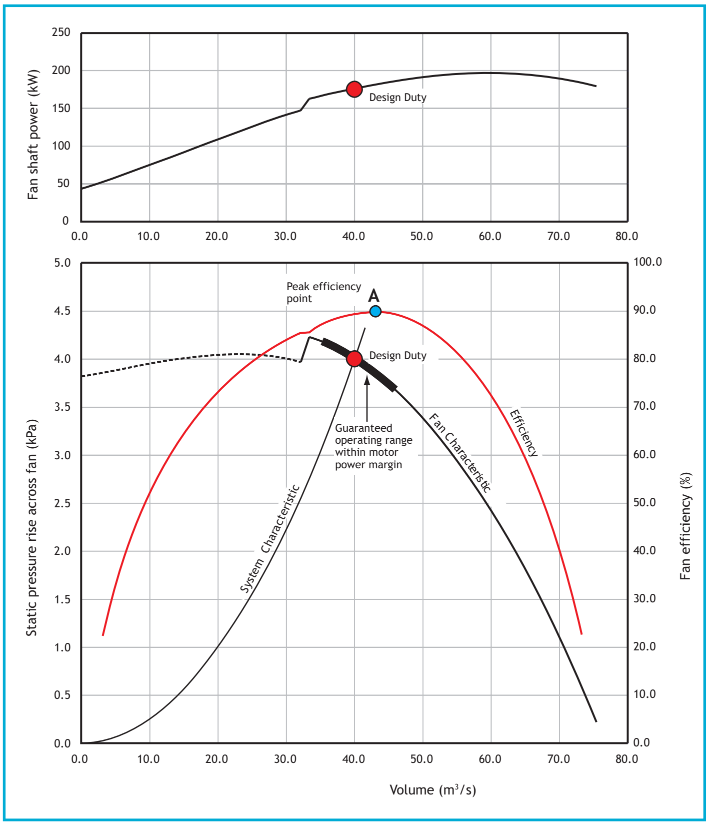


Figure 9 Fan characteristics at fixed speed

2.6 The fan laws

It is not practical to test the performance of every size of fan in a manufacturer's range at all speeds at which it may be designed to operate, and with every gas density it may be required to handle.

The performance of geometrically similar fans of different sizes or speeds can be predicted accurately enough for practical purposes using the fan laws. These laws apply to the same point of operation on the fan characteristic. Where a fan's characteristic is known, the laws can also be used to predict a new pressure volume characteristic curve at a different impeller diameter or speed.

The fan laws are most often used to calculate the changes in flow rate, pressure and power of a fan when the size, rotational speed or gas density is changed.

For a system where there is no change in fan size or in density of the air or gas, and pressure loss increases in proportion to the square of the flow:

- Inlet volume flow (Q) varies in proportion to the speed of the fan (n), i.e. $Q \propto n$
- Fan total pressure and static pressure vary in proportion to the square of the fan speed, i.e. p_t or $p_s \propto n^2$
- Air power (P) (total and static) and the impeller power vary in proportion to the cube of the fan speed, i.e. $P \propto n^3$.

For geometrically similar airways, the fan laws can be used to calculate changes in flow rate, pressure and power when the size, rotational speed or gas density changes. Figure 10 shows how the effects of a fan speed increasing or decreasing can be evaluated, by showing fan characteristics above and below normal speed that are produced using the fan laws.

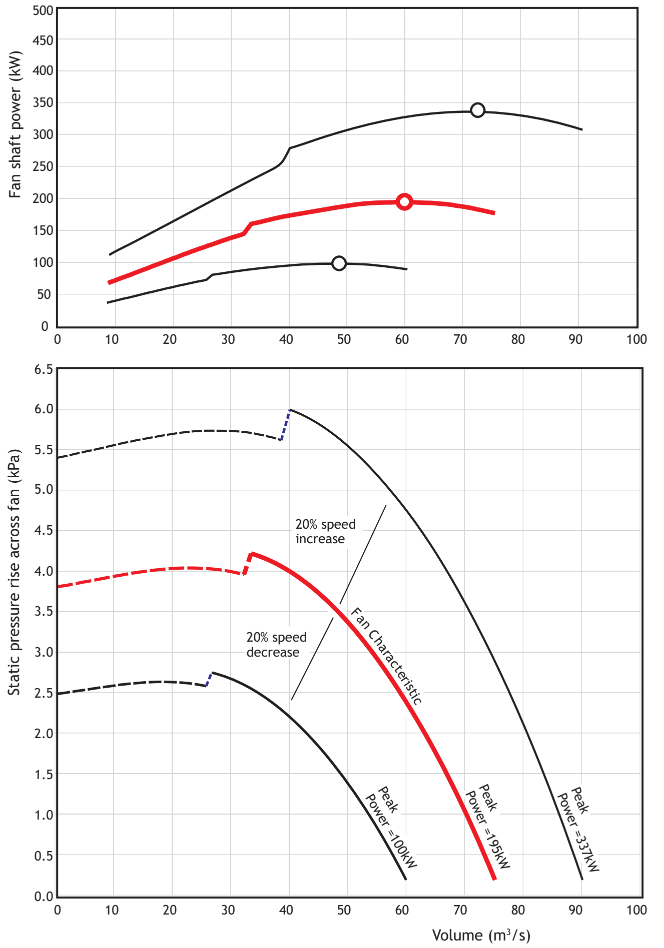


***Figure 10** Demonstration of the fan laws*

2.7 System resistance laws

When air is moved through a ducted system, the energy transferred to the air by the fan is progressively lost by:

- Friction of the air against the duct walls
- Turbulence at bends, dampers and changes of duct section
- Through heaters, filters or other items of equipment in the system.

This loss of energy is evident by the decrease in pressure (see Figure 11).

The loss of pressure due to all these sources, known as the system resistance, is for most practical purposes proportional to the square of the velocity at the point of loss.

Therefore, for a fixed system, it may be said that the pressure (p) required to pass a given volume of air (Q) through the system will vary in proportion to the square of the volume flow rate, i.e. $p \propto Q^2$. This means that, for a fixed system, the greater the airflow, the more pressure is required. Hence, to double the airflow, four times as much pressure has to be produced by the fan.

For example, if the initial flow rate is $6m^3$/second at a pressure of 3kPa and it is required to double this to $12m^3$/second:

$$\frac{p_1}{p_2} = \frac{(Q_1)^2}{(Q_2)^2}$$

$$p_2 = \frac{p_1 (Q_2)^2}{(Q_1)^2} \quad \text{i.e.} \quad p_2 = \frac{3 \times 12^2}{6^2} = 12\text{kPa}$$

This is true only for a fixed system and a constant air density. Should the system be altered (e.g. by closure of a damper), the above laws do not apply directly.

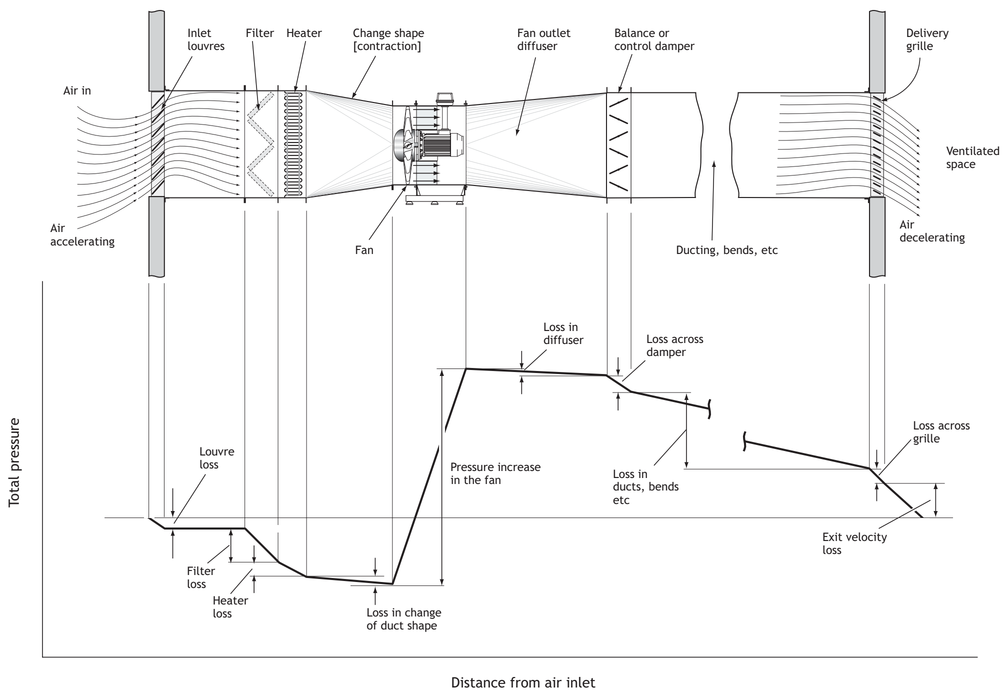


Figure 11 Change in total pressure in a typical fan system

3 Selecting energy efficient fans and fan systems

This section describes the factors and considerations to be taken into account when selecting a fan and/or fan system that is efficient both in terms of its performance and its energy consumption. A checklist of energy saving measures is given in Section 5.

This section stresses the importance of:

- Selecting the correct type and rating of the motor used to drive the fan
- Determining the air velocity as part of the design process
- Minimising pressure drop through the ductwork installation
- Selecting the most appropriate fan for a particular application
- Correct installation
- Regular maintenance of the fan and fan system
- An annual system review to ensure that maximum energy savings are maintained.

The section also discusses the different types of control systems for fans, and the factors that need to be taken into account when deciding which type to use.

A detailed table is provided that summarises the different fan types, their efficiencies, performance characteristics and typical applications.

3.1 Basic fan design and efficiency

Fan design is both an art and a science. When designing efficient impellers, most manufacturers start out by testing a series of impellers with the aim of producing a set of aerodynamic shapes that:

- Cover the required pressure/volume envelope
- Develop a good efficiency across as wide a zone as possible
- Are not sensitive to small geometrical changes
- Preferably have a non-overloading power curve (where the impeller design permits)
- Are relatively easy to manufacture with a low cost (probably the most important to the manufacturer).

Although it is relatively easy to design an impeller to satisfy a particular pressure/volume duty, it is difficult to achieve this with a high efficiency while making it cost-effective to manufacture. This means that one manufacturer's fan may satisfy the duty requirements with a much higher efficiency than another manufacturer's.

The way to save energy when using fans appears simple – use more efficient fans. However, it is not that straightforward. Modern higher efficiency motors have a relatively flat efficiency curve with load, and improving the motor efficiency means improving the efficiency over the whole operating field[2]. The same does not apply to fans – the efficiency curve is far from constant and there can be a difference of 30% between peak and low efficiency in the fan's working range. In addition, the energy use of similar fans performing the same duty but from different manufacturers can vary by up to 30%. It is therefore important to select a fan that is operating as near to its peak efficiency as possible.

2 See GPG002 Energy savings with electric motors and drives. GPG002 and other Action Energy publications mentioned throughout this guide are available free of charge through the helpline on 0800 58 57 94 or via the Action Energy website at www.actionenergy.org.uk.

Fan specifications should stipulate the use of both a high efficiency fan and a higher efficiency motor (either classified as Eff 1[3] or one eligible for Enhanced Capital Allowances[4]) to achieve maximum energy savings during the operational life of the equipment. Advice on motor selection is given in Section 3.1.1.

When selecting a fan and specifying a fan installation, it is also important to consider whole life costs. These consist of the initial cost of the fan, energy costs, plant life expectancy, the cost of maintenance and other operational issues, and disposal costs. Appendix B explains how to calculate whole life cost.

3.1.1 Sizing and selection of motors

Improved sizing can significantly reduce both the capital and running costs of electric motors. Motors are often rated well above the power levels at which they operate. Modern motors are designed for maximum efficiency at 75% full load, although there is minimal variation in efficiency between 50% and 100% load. Significant reductions in efficiency occur at 25% load or less.

As an example, a basic duty may suggest a delivered power requirement of 7.5kW. Typically, the designer may specify a 10% design margin and the project engineer may apply a further 10% contingency. Applying these two 10% increases would suggest a specification of 9.1kW. However, as 9.1kW is not a standard rating, an 11kW motor would have to be selected. For the duty required, the selected motor would actually operate at two-thirds or less of its rated output.

Oversizing motors increases:

- The capital cost of the motor
- The capital cost of matching switchgear and cabling
- The capital cost of power factor correction equipment
- The running costs due to lower efficiency.

Higher efficiency motors (HEMs) are designed to minimise the inherent losses and can save, on average, 3% of energy consumption compared with standard motors. They are also quieter.

Useful Action Energy publications on motors

GPG002 Energy savings with electric motors and drives
GIL056 Energy savings from motor management policies
GPCS222 Purchasing policy for higher efficiency motors
GAMBICA1 Making the most of the Climate Change Levy package

3 Under a voluntary agreement between the EU and CEMEP (the European trade association for motor manufacturers), 1.1-90kW 2+4 pole motors are classified as Eff 1, Eff 2 and Eff 3, with Eff 1 being the most efficient.

4 Qualifying motors published on the Energy Technology List can attract Enhanced Capital Allowances on the capital cost of the product. For more information, call the helpline on 0800 58 57 94 or visit www.eca.gov.uk

3.2 The fan and system

3.2.1 System resistance

An air system may either consist of just a fan with ducting, or it may be more complicated with additional components (as shown in Figure 1). The fan is the component that provides energy to the air stream to overcome the resistance to flow of the other components in the system.

Every system has a resistance to flow; this usually differs from other systems and depends on the individual components from which it is assembled. The characteristic curve of a typical 'fixed system' is a parabola given by the relationship:

$p \propto Q^2$ where p = pressure and Q = flow rate

For a fixed system, an increase or a decrease in the system resistance results in a decrease or an increase in the volume flow rate along the given system curve. Figure 9 shows an example of fan characteristics at fixed speed.

3.2.2 Influence of velocity on design

Velocity is the first choice to be made when designing a fan system.

Low velocity systems should be used where possible, because they produce low pressure losses and require the least fan power, thus minimising energy use. However, this also means designing ductwork with the largest cross-sectional area. Table 1 summarises the options.

For further advice, see GPG257 Energy efficient mechanical ventilation systems.

System velocity			Advantages	Disadvantages
	Typical filter and coil face velocities (metres/second)	Typical main duct velocity (metres/second)		
Low	<2	5	Low fan power Low noise	Higher capital cost More space
Medium	2-3	8	Lower capital cost Requires less space	More fan power Increased noise
High	>3	≥12	Least capital cost Least space	High fan power High noise

Table 1 *Advantages and disadvantages of low, medium and high velocity systems*

3.2.3 Design to minimise pressure loss

The characteristics of any fan are affected by the installation to which it is connected. This may be ductwork or another means of conducting the air or gas through the space. The effect of the ductwork on the fan performance is called the system effect. When designing ductwork systems and selecting fans, it is important to minimise the influence of the installation, as this can adversely affect the aerodynamic performance.

A major design issue, when considering the system pressure loss, is where to locate the fan: the fan should be located as close as possible to the application to minimise the length of ductwork. In addition, pressure losses can be reduced by[5]:

- Good design at entry from and discharge to the atmosphere
- Minimising friction in duct lengths
- Close attention to detail at changes of duct areas and shape
- Minimising bends and changes in direction
- Using radius bends in preference to right-angled bends
- Good design when dividing flow into branches
- Using Y-junctions in preference to T-junctions
- In rectangular ductwork, keeping the aspect ratio as near to one as possible
- Avoiding obstructions,
- Good design and installation of filters, heaters, coolers, grilles and louvres
- Keeping the change of pressure between atmospheric and that at the inlet and outlet as low as possible.

Approved Document L2[6] of the Building Regulations imposes performance criteria covering the maximum allowable fan power for mechanical ventilation and air conditioning systems in buildings other than offices. For new buildings, the specific fan power (SFP)[7] should be no greater than 2 watts/litre/second. For refurbished installations or where an existing ventilation system is altered, the SFP should be no greater than 3 watts/litre/second. For office buildings, the performance criterion is the Carbon Performance Rating (see Approved Document L2 for more details).

3.2.4 Selection of the fan for the system

Fan selection entails matching the fan performance curve to the system resistance curve to find the fan that will develop the equivalent and necessary pressure to meet the system requirements, i.e. the fan will deliver the designed flow rate when installed in the system (see Section 2.5).

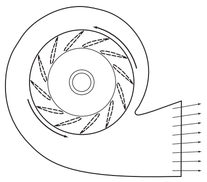
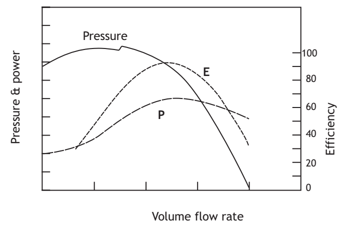
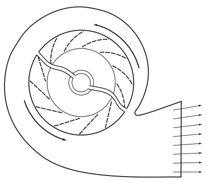
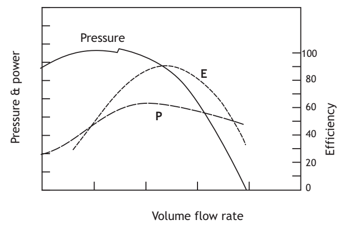
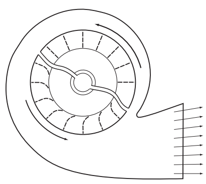
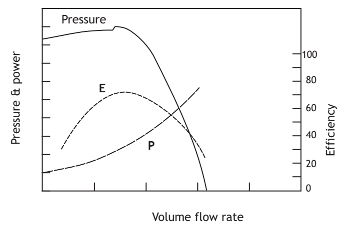
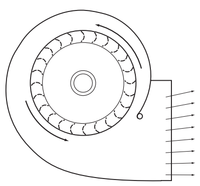
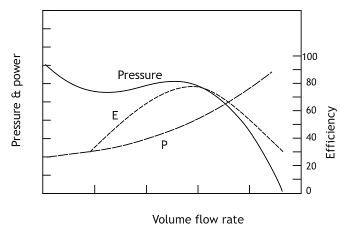
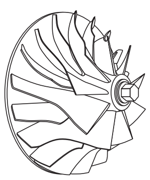
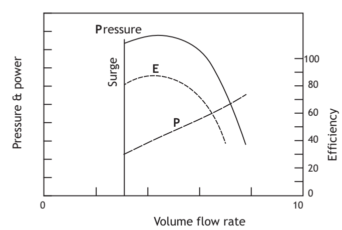
System designers should try to achieve minimum pressure and best velocity distribution. A specialist fan supplier should be responsible for selecting the most efficient fan.

Table 2 shows 16 different fan types together with performance curves and a summary of typical applications.

5 For further information, see CIBSE Guide B3 Ductwork (see Appendix C for contact details).

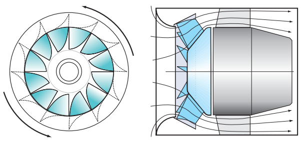
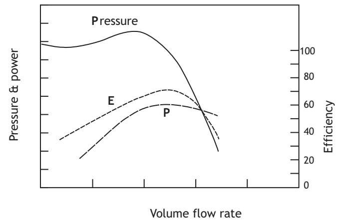
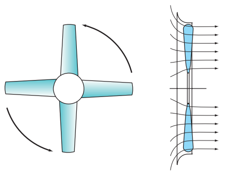
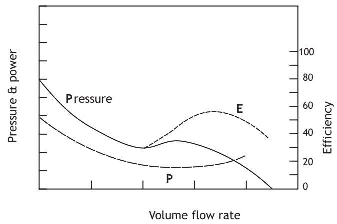
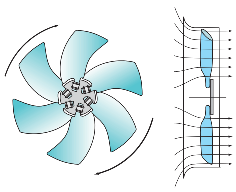
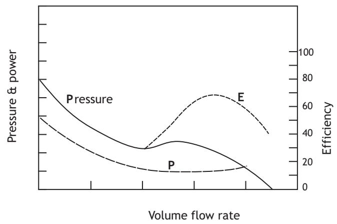
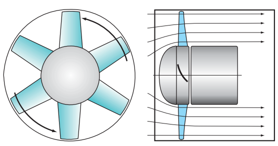
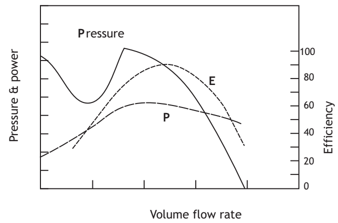
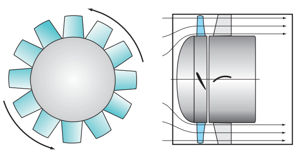
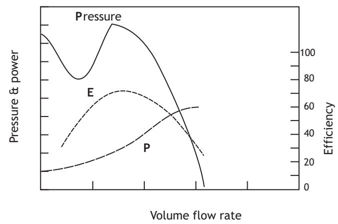
6 For details, see Appendix C.

7 See a definition, see the glossary in Appendix A.

Type	Efficiency	Performance characteristic	Applications	Fan characteristic
Centrifugal aerofoil 	Highest efficiency of all centrifugal fan designs. Air leaves the impeller at a velocity less than the tip speed and relatively deep blades provide for efficient expansion within the blade passages; 10–16 blades of aerofoil contour curved away from the direction of rotation. For a given duty, this is the highest efficiency machine.	Peak efficiency of up to 90% occurs at 50–65% of full-open volume flow. The high efficiency zone also corresponds to a stable area of the operating curve. The absorbed power becomes lower towards a free delivery. The power curve is of a non-overloading type.	General use for heating, ventilation and air-conditioning (HVAC) systems. Usually applied only to large systems where the power savings can be significant. Can be used on low-to-medium and high-pressure systems. Used in large sizes, up to around 4m diameter for non-erosive duties in most industrial applications.	
Centrifugal backward inclined plate blade 	Efficiency is only slightly less than that of aerofoil fans. Backward-inclined or backward-curved blades are single thickness; there are 10–16 blades curved or flat-inclined away from the direction of rotation. Efficient for the same reasons as given for the aerofoil fan above.	The operating characteristics of this type of fan are similar to the aerofoil design described above. Peak efficiency, which can be up around 85%, is only slightly lower than the aerofoil design. Power curves are normally of the non-overloading type.	Same HVAC applications as the aerofoil fan. Also extensively used in industrial applications. Can cope with medium erosive gases and, in very onerous applications, it can be fitted with sacrificial erosion liners.	
Centrifugal radial or radial-tipped 	Simplest centrifugal fans, but also the least efficient. Have the highest mechanical strength and the impeller is easily repaired; 6–16 blades, shrouded or unshrouded. For a given duty point, this fan requires medium speed.	Higher pressure characteristics than the fans above due to the higher velocities of the fluid leaving the impeller. The pressure volume curve may have a break just left of the peak pressure, but this is usually not sufficient to cause difficulty. Efficiencies are normally less than 70%. The power curve is of the overloading type; care is necessary when selecting the driving motor.	Used primarily for handling gases where particulate matter is present and has a tendency to adhere to the impeller blades. Has a self-cleaning advantage when used in handling gases with a particulate content. The flat-bladed versions can be easily protected with sacrificial erosion liners. Not often found in HVAC applications.	
Forward curved 	Efficiency is less than an aerofoil or a backward-curved plate-bladed fan. Usually has a lightweight impeller in a low-cost construction. The impellers normally have 24–64 shallow blades, with the inlet and the outlet edges curved forward in the direction of impeller rotation. The velocity of the air leaving the impeller is normally higher than the peripheral speed of the impeller; thus, the impeller design is the smallest for a given duty. The impeller has limited mechanical strength and is only normally used for low-speed applications and for small sizes.	The pressure volume curve is less steep than that of a backward-curved impeller, and there is a depression to the left of the peak pressure. The power curve is of a constantly rising type and care is therefore necessary when selecting the drive motor.	Used primarily in low-pressure HVAC applications, such as domestic heating systems and air conditioning units.	
Mixed flow centrifugal exit  *Courtesy of Fläkt Woods Ltd*	Axial entry, mixed flow blades provide a centrifugal output flow, normally into a volute casing. Machined from steel or aluminium, these impellers are normally unshrouded. They are usually mounted on the high-speed output shaft of a gearbox and generally run at speed of over 3,000rpm.	High-pressure development can be combined with high efficiency. Normally fitted with either close-coupled inlet or discharge variable geometry flow control vanes. The power characteristic is of the overloading type; care is therefore necessary when selecting the drive motor and designing the drive train. The unstable region on the output characteristic (commonly referred to as surge) produces severe duct pulsation and should be avoided.	This design is an extension into the fan field of the high-strength, high tip-speed designs used for turbo-compressors. Finds a place in high-power applications in heavy industry.	

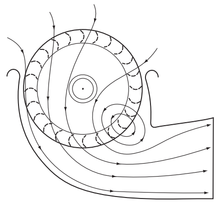
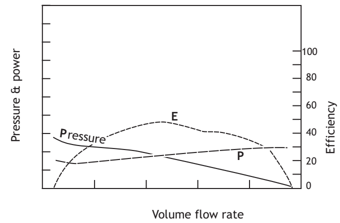
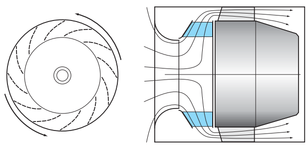
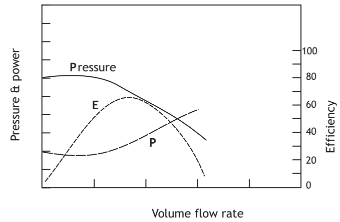
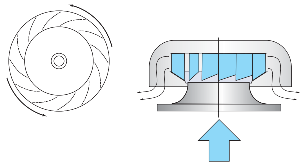
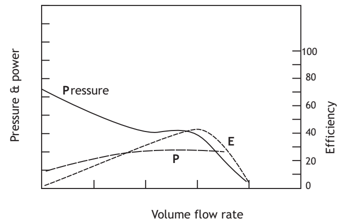
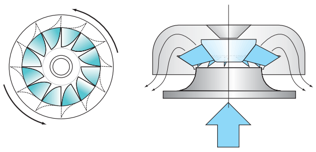
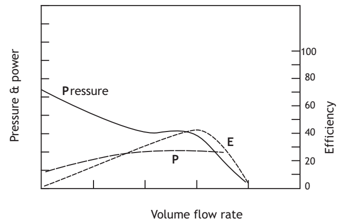
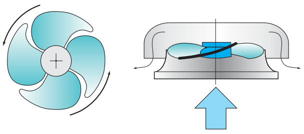
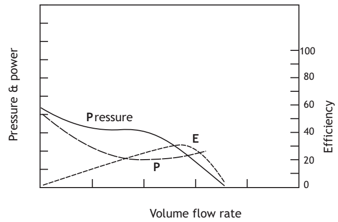
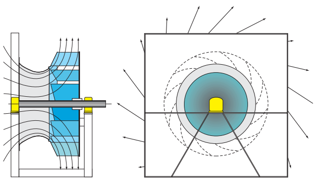
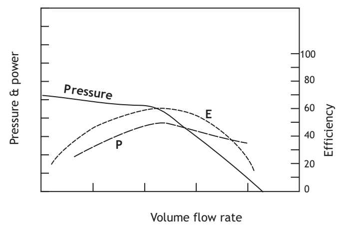
Key: E = efficiency P = air power

***Table 2** Fan types and applications*

Type	Efficiency	Performance characteristic	Applications	Fan characteristic
Mixed flow axial discharge 	Similar to an axial fan but with a radial flow component. The impeller flow passage is conical, with a larger diameter at the outlet. The rotation imparts both aerodynamic lift from the blades and a centrifugal component. The flow from the impeller discharges into an annular chamber, where stationary vanes can be fitted to reduce the whirl component.	A significant part of the pressure is developed by the centrifugal action. Its static pressure generating capacity is higher than an axial fan rotating at the same speed.	Although it is possible to reach efficiencies and noise levels comparable with those of a backward-curved centrifugal fan with a more compact in-line casing arrangement, these fans are not popular due to their relatively high costs and the limited flexibility in output duty.	
Propeller 	Efficiency is low. Impellers are usually of an inexpensive construction and limited to low-pressure applications. Impeller is usually two or more blades of single thickness and attached to a relatively small hub. Energy transfer is primarily in the form of velocity pressure.	High flow rate but very low-pressure capabilities, with a maximum efficiency of around 60% being achieved close to free delivery. The discharge from this type of fan has a large rotational or swirl component due to the action of the blades and because there are no flow straightening vanes.	Used for low-pressure high-volume air moving applications, such as circulation within a room space or ventilation through a wall without the use of ducting.	
Plate-mounted axial flow/partition 	The efficiency of this type of fan is much improved by the incorporation of a close-fitting shroud and inlet bell. Complex aerodynamic blade designs are also used and commonly overlap on some arrangements. Blades are normally fabricated from plastic and/or reinforced glass fibre. Fans can be up to 15m in diameter, but generally operate at low speeds (normally less than 100rpm).	High flow rate, low-pressure capability with a maximum efficiency of around 70%. The rotational flow-field after the impeller is minimised due to the lower rotational speeds.	Normally used in all types of cooling applications in conjunction with a close-coupled tube or fin type heat exchanger	
Tubeaxial 	Somewhat more efficient than a propeller fan design and capable of developing a more useful static pressure rise. The blade numbers vary from around 3 to 12 and the hub is usually less than 50% of the blade tip diameter. Blades can be of aerofoil or single thickness cross-section.	High flow combined with medium-pressure generating capability. The performance curve shows a dip in the pressure generating capacity left of the peak pressure and operation in this zone should be avoided. The discharge air pattern is annular and exhibits a distinct swirling motion as it leaves the impeller. There are no stationary down-stream guide vanes to recover this rotational flow component.	Used in low-to-medium pressure dual HVAC applications where the air distribution downstream of the fan is not critical. Also used in some industrial applications, such as drying ovens, paint spray booths and fume exhaust systems.	
Vaneaxial 	Well-designed blades permit a medium pressure capability with high efficiency. The most efficient of these types of fans employ aerofoil blades. Blades can be fixed or adjustable at rest, or even in motion using mechanical or hydraulic blade pitch adjustment systems. The hub diameter is normally around 50% of the blade tip diameter.	The performance curve includes a dip, caused by aerodynamic stall, to the left of the peak pressure; this should be avoided. Special anti-stall chambers can be fitted close to the blade periphery where there is a requirement to operate the fan at lower flow. Downstream guide vanes are used to correct the circular motion imparted to the air by the impeller, and to improve the static pressure produced. Two impellers can be designed to run on the same shaft to form a two-stage unit, approaching double the static pressure capability.	Used in general HVAC systems in low, medium and high-pressure applications, where an in-line duct arrangement is an advantage. Air velocity distribution on the downstream side is good. Also used in industrial applications. More compact than a comparable centrifugal-type fan.	

Key: E = efficiency P = air power

Table 2 *Fan types and applications continued*

Type	Efficiency	Performance characteristic	Applications	Fan characteristic
Cross flow 	Impellers similar to those of multi-vane forward curved centrifugal fans are used. The action of this type of fan is radically different. A vortex is formed and maintained by the blade forces and has its axis parallel to the shaft and near to a point on the impeller circumference.	Efficiency is low but the fans are quiet for their duty. To obtain a reasonably efficiency, an adequate outlet diffuser is necessary, since most of the static pressure is derived from the conversion of the high velocity pressure leaving the impeller.	Improvements in casing design have brought this type into prominence for use in certain small domestic appliances. They present long, narrow rectangular shape of inlets and outlets.	
Tubular centrifugal 	This fan usually has an impeller similar to the aerofoil, backward-inclined or backward-curved plate-bladed units described above. Due to the annular casing constraint, this type of fan has a lower efficiency than a conventional 'scroll casing' type.	Performance is similar to backward-curved fans, except the pressure-volume characteristic is depressed due to the 90˚ change of direction at the impeller exit. The efficiency is lower than an equivalent backward-curved, conventional scroll-casing type of fan. Some designs may show a dip in the pressure curve similar to an axial unit.	Used primarily for low-pressure return air systems in HVAC applications. The 'straight-through' casing design offers some advantages.	
Roof ventilator-centrifugal 	Many models use aerofoil or backward-inclined plate-bladed impellers as described above. The impellers are designed to provide high volume flow at very low pressure. Mixed flow impellers, as described above, can also be used.	The fans are normally designed without connecting ductwork and therefore operate against a very low static pressure. Only static pressure and efficiency are shown for this type of fan.	Used for low static pressure exhaust systems, such as general factory, kitchen, warehouse, and commercial installations, where the low static pressure rise limitation can be tolerated.	
Roof ventilator-mixed flow 	Multi-bladed shrouded mixed flow impellers with a 45˚ outlet flow offer a good match with the weather cowl.	The fans are normally designed without connecting ductwork and therefore operate against a very low static pressure. Only static pressure and efficiency are shown for this type of fan. The fan units generally have lower dBA noise levels compared with axial units and as such sound quieter.	Used for low static pressure exhaust systems, such as general factory, kitchen, warehouse, and commercial installations, where the low to medium static pressure rises are required.	
Roof ventilator-axial 	A large variety of propeller designs are used where the duty requires high volume flow at low static pressure.	The fans are normally designed without connecting ductwork and therefore operate against a very low static pressure. Only static pressure and efficiency are shown for this type of fan.	Used for low static pressure exhaust systems, such as general factory, kitchen, warehouse, and commercial installations, where the low static pressure rise limitation can be tolerated.	
Plenum fan 	Many models use aerofoil or backward-inclined plate-bladed impellers as described above. The impellers are designed to provide high volume flow at medium pressures. Efficiencies are low.	These fans are unique in that they do not have a scroll casing. The discharge from the impeller is unconstrained and enters the room or the enclosure directly. Without a scroll casing, a significant amount of the kinetic energy in the impeller discharge air stream is not converted to useful static pressure and is lost. The performance of the fan can be affected by its position within the room or enclosure.	Used mainly in air handling units.	

Key: E = efficiency P = air power

Table 2 *Fan types and applications continued*

3.3 Integration of the fan with the system

3.3.1 Site installation and set-up

Even after a manufacturer has designed, built and tested a fan that satisfies the client's performance requirements (i.e. pressure, volume, power absorbed, etc.), significant problems can arise if the fan is incorrectly installed (the fan supplier is often not responsible for installation). Certain aspects, such as uniform tip clearance on an axial fan and inlet cone positioning and penetration on a centrifugal fan, can have a significant impact on the installed performance and efficiency of the fan.

3.3.2 Installation effects on fan performance

The installation of ductwork close to a fan has a significant effect on the performance of both the fan and the ductwork. Because the magnitude of this effect is often unknown, contingencies may be added to the calculated fan performance to allow for shortfalls in performance due to installation effects. This can result in increased capital and running costs, and a system that is not operating at its design condition.

Assuming the fan is rated correctly, the three most common causes of poor fan performance due to the effects of the installation are:

- Non-uniform inlet velocity (see Figure 12)
- Swirl at the inlet (see Figure 13)
- Improper outlet (see Figure 14).

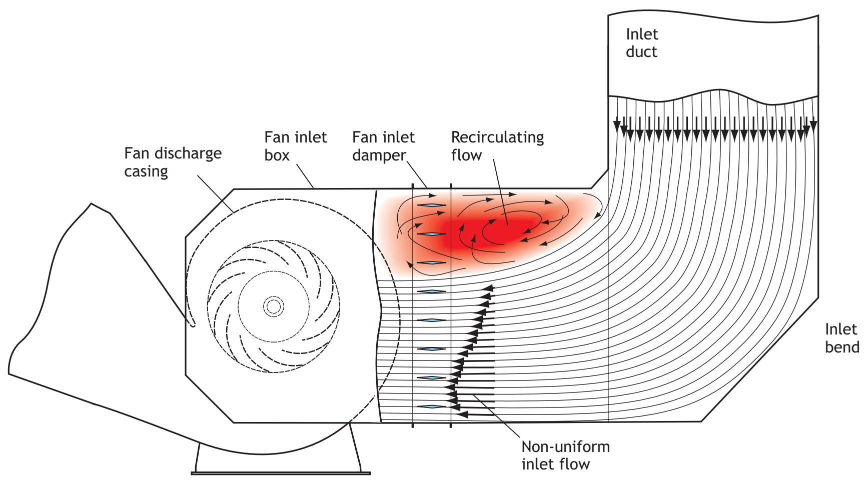


Figure 12 *Non-uniform inlet velocity*

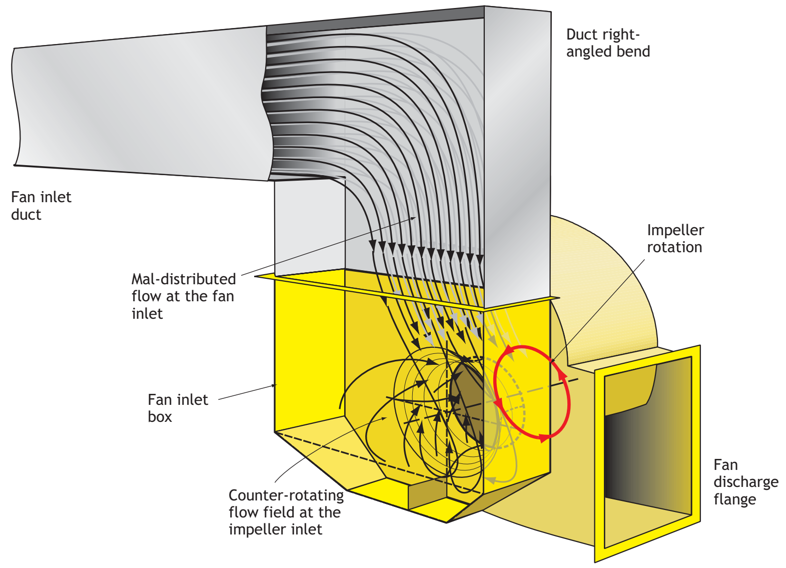


***Figure 13** Swirl at the inlet*

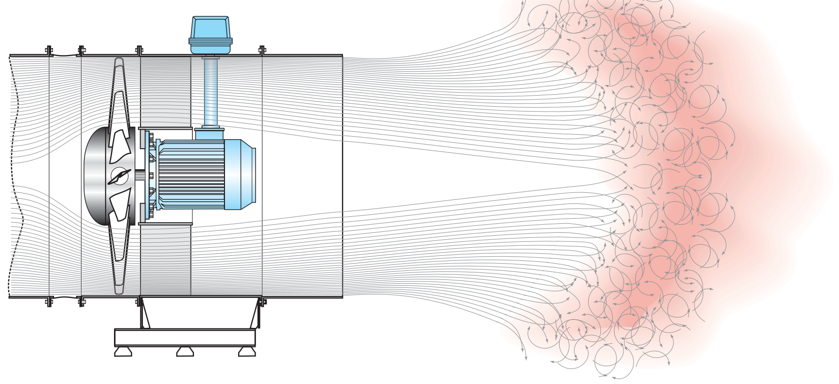


***Figure 14** Improper outlet*

Inlet flow distribution is paramount. If the flow is badly distributed, fan performance will be significantly reduced. The ductwork adjacent to the fan can have a considerable effect on the fan performance, and the fan manufacturer and system designer should discuss this issue. Example problems include restrictions caused by fan inlets located too close to walls, obstructions and the effects of plenums.

Figure 15 illustrates deficient fan/system performance resulting from undesirable flow conditions, such as:

- Where the characteristics of the installed system differ significantly from the designer's intent
- When design calculations made insufficient allowance for the effects of accessories and equipment
- Having reduced airflow due to dirty filters, ducts and coils.

Such conditions alter the aerodynamic characteristics of the fan so that its full potential is not realised. One bad connection can reduce the performance of a fan far below its rated capacity!

Figure 15 demonstrates the problems that can occur if the system designer fails to ensure that the fan characteristic and the system characteristic are suitably matched.

- The dotted line in Figure 15 to the left of the design system characteristic shows a pressure drop in the system that is 40% above the design value. This results in lower volume flow, increased pressure and the danger of the fan failing to operate at all because it is close to the point of stall.

- The dotted line in Figure 15 to the right of the design system characteristic shows a pressure drop 40% lower than the design value. Here, the fan operates at reduced efficiency, thus delivering an excess volume of air.

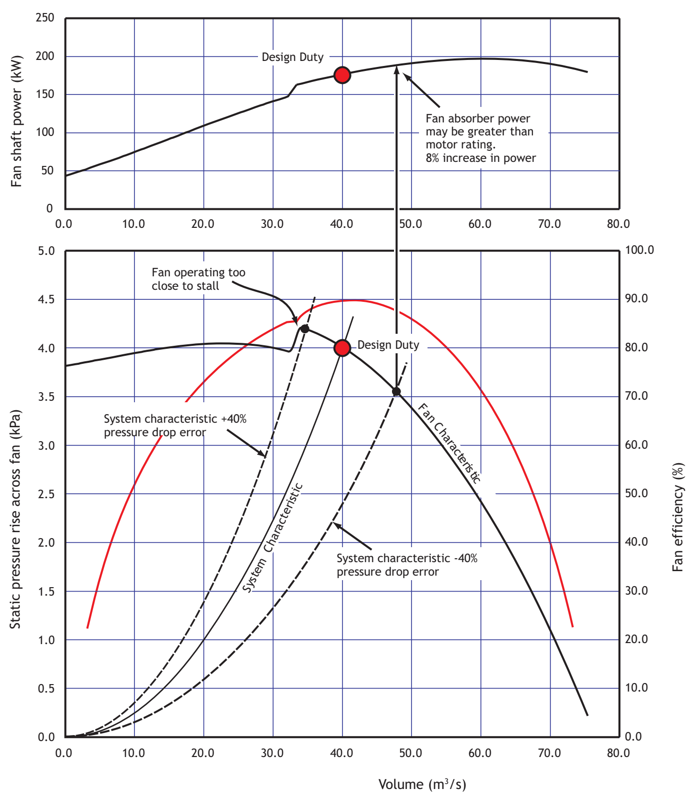


Figure 15 Deficient fan/duct system performance

3.4 Controlling flow rates through a fan system

It is often necessary to control the rate at which air is moved through a fan system. This may be:

- A once-only correction to compensate for initial errors in calculation
- An intermittent control to give, for example, a summer and winter condition
- A continuously variable adjustment to maintain an environment or to supply a process.

The fan designer's job is to produce fans that achieve the highest possible part-load efficiency.

The rate of airflow through a system is governed by the intersection of the system resistance line and the fan performance characteristic (see Figure 9). Control can be achieved by changing the effective resistance of the system or altering the performance characteristic of the fan. The method chosen will depend largely on the savings in absorbed power at reduced flow rates balanced against initial cost.

3.4.1 Control by system design

The simplest means of adjustment is to use a valve or damper at a suitable point in the ducting system (see Figure 16). Closing the damper increases the resistance to flow and the quantity of air falls as dictated by the fan characteristic. Dampers can either be operated manually or using a control system.

Although cheap to install, the inherent pressure loss across a damper is a waste of energy, may create noise and should be avoided. A more efficient control method is to adjust the performance of the fan itself (see Section 3.4.2).

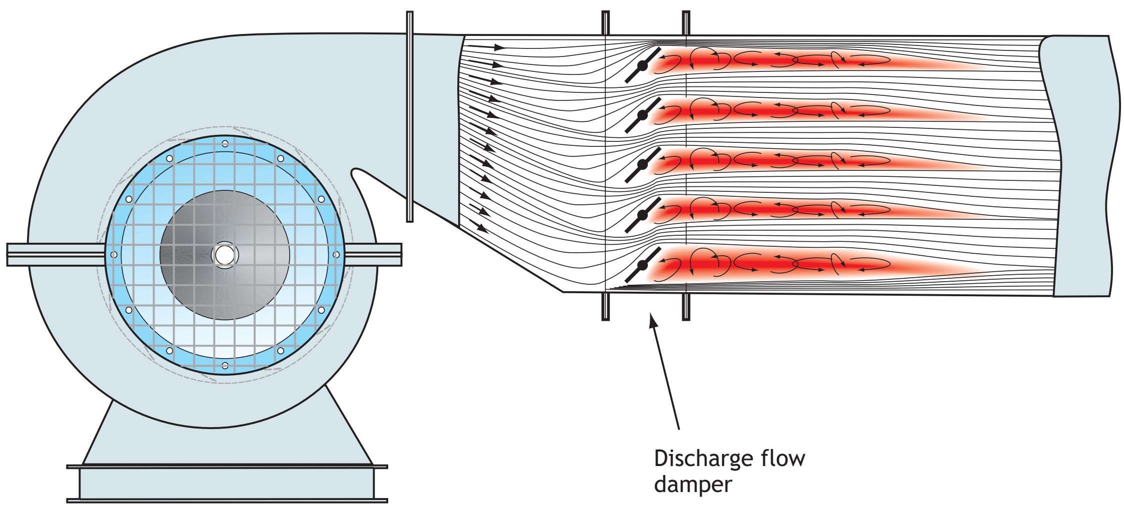


Figure 16 *Fan discharge flow damper*

3.4.2 Control by fan characteristic

Continuously variable controls allow the fan to operate at the highest possible efficiency even at part-loads. However, they function only if the system resistance curve follows the square law (see Section 2.6) and goes through points of zero pressure and flow. If the system resistance does not follow a square law, reducing the fan speed may result in the fan reaching a stall condition with poor efficiency.

There are three main types of continuous control of fan performance.

- **Speed control**

  One of the most efficient methods of controlling the performance of a fan is to vary its running speed. When working in a constant resistance duct system (i.e. square law system pressure), the point of operation on the fan's characteristic is unchanged as the speed varies. This has the advantage of maintaining the fan's efficiency, resulting in a corresponding maximum reduction in power consumption and fan noise level as the speed is reduced (see Figure 17).

This method provides a suitable means of controlling the speed of the fan, either by varying the speed of the prime mover or by changing the ratio of the drive.

Examples of speed control methods include:
- Multispeed or variable speed electric motors
- Variable speed gearbox
- Fluid coupling
- Magnetic coupling
- Variable ratio pulleys and belt drive.

When assessing the power saving using these methods, it is necessary to take account of the change in efficiency of the prime mover and drive (this may vary with speed or load). If electrical, magnetic or mechanical slip is involved, the overall effect is occasionally to reduce the power input to the prime mover in proportion to the square of the speed, while power output to the fan impeller varies in proportion to the cube of the speed; the efficiency of the speed conversion is equal to the ratio of output and input signals.

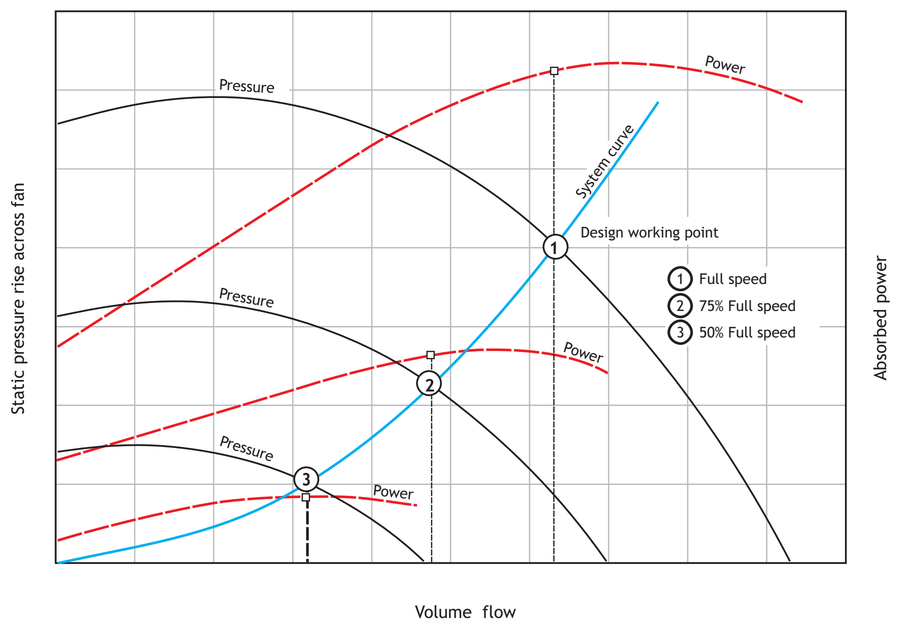


Figure 17 Flow control by speed regulation

- **Inlet vane control**
  This method involves introducing specially designed adjustable vanes into the air stream entering the fan inlet, to generate a swirl of air in the direction of the impeller rotation. This reduces the performance capability of the fan, which shows progressively reduced pressure/volume and power curves as the vanes are closed. This in turn moves the working point down the system resistance curve.

- **Blade angle control (axial fans only)**
  This very efficient method, which is currently confined to axial fans, involves adjusting the blade pitch angle while the fan is running. The angles of all the blades are altered simultaneously.

3.4.3 Factors affecting the choice of control method

The first step is to assess the saving in power over the life of the machine. The next step is to compare these savings against initial outlay and maintenance costs, while bearing in mind the degree of control required and the frequency of operation.

Factors that can influence the choice of control method include:

- Initial manufacturing and installation cost
- Maintenance and replacement cost
- Power saved
- Degree of control required (stepped or continuous)
- Accuracy and repeatability of the control settings
- Range of flow over which control is required
- Temperature, toxicity or corrosiveness of gas handled
- Period of time over which each setting is effective
- The control system itself.

Further information on methods of fan control is given in the Fan Application Guide published by the Fan Manufacturers Association[8].

3.5 Maintenance

Regular maintenance of any fan installation is essential to ensure it continues to operate at maximum efficiency and hence minimum energy use.

3.5.1 Good practice

Suggested routine maintenance tasks are summarised in Table 3 (on page 27). These should be carried out at a frequency determined by the specific installation requirements.

3.5.2 System review

The complete system should be reviewed annually, and its performance should be checked to ensure that it meets current requirements and matches the results of commissioning.

If the system is not meeting requirements, then investigations should be carried out to identify the cause(s). Examples of measures to overcome poor performance include changing:

- The pitch angle of an axial impeller if the flow rate needs increasing or decreasing
- The pulley ratios on a belt drive to adjust the operational speed
- The impeller to increase or decrease the volume flow within the limitations of the existing motor power (only in extreme cases).

The energy saving checklist in Section 5 also offers useful suggestions. The original equipment supplier should be consulted for further technical advice.

8 See Appendix C for contact details.

	Check	Remedial action
1	Examine fan casing and check it is free from corrosion and dirt. Check bolts and fastenings are in place and secure. Check flexible connections to ductwork or other components are secure, undamaged and installed correctly.	Repair or replace heavily corroded fan casings. Clean lightly corroded casings thoroughly and repaint.
2	Check that the fan impeller is free from cracks, corrosion, erosion, dust build-up or other damage. Check keyways and fastenings are secure and there is no movement of the impeller on its shaft. Check the impeller is not out-of-balance.	Repair or replace cracked or damaged impellers. Remove dirt or corrosion from the impeller.
3	Check fan shaft bearings are in good condition and lubricated properly. Lubricants should: • Be suitable for the normal bearing operating temperature and surrounding ambient conditions • Show no signs of overheating, dilution, contamination or over-use.	Replace faulty fan shaft bearings
4	Check the tension of belt drives. Examine belts for signs of wear or fraying.	Adjust belt drive tension where necessary. Replace belts as a complete set (if required).
5	Check alignment of drive pulleys is in accordance with the manufacturer's specification.	If necessary, correct alignment.
6	Check that drive pulleys are secure on their shafts.	If necessary, secure drive pulleys.
7	Check that system elements are clean and free from obstruction.	Replace system elements if necessary.

Table 3 *Maintenance good practice for fan installations*

4 Fan applications

This section highlights potential opportunities for energy saving in two common fan applications:

- Mechanical draught fans, typically in coal-fired power generation
- Dust and fume extraction using either local exhaust or dilution methods.

4.1 Boiler mechanical draught fans

Gas, oil and coal-fired boilers are used extensively to provide heating, hot water and steam for process applications, and in the generation of electrical power. In all cases where a fuel is being burnt, fans are used to provide combustion air and to transport exhaust gases. In some coal-fired boilers, they are used to transport and deliver the fuel into the furnace (see Figure 18).

The characteristics of the three main types of fans are summarised in Table 4. The fans used to deliver the combustion air to the furnace are known as forced draught fans. In larger units, additional fans transport the exhaust gases out of the boiler unit. Such fans are known as induced draught fans and normally handle hot gas at around 140˚C. On larger coal-fired plant, primary air fans are used to transport the powdered coal (typically the constituency of talcum powder) into the furnace.

For industrial boilers, the absorbed power of an individual fan is in the range of 100kW to 10,000kW, depending on the size of the plant. The fans, which are used to transport the air and exhaust gas through the boiler furnace and ducts, are sized not only to cater for the flow requirements, but also to overcome the pressure drop through the system.

The amount of air that a fan handles is a function of both the type of fuel used and the output required from the boiler.

Type	Description
Forced draught fans (FD)	These fans draw atmospheric air and deliver it, within a ducting system, to the combustion furnace. In larger plants, the air is supplied to a heat exchanger where it is preheated (normally to around 300˚C) before entering the furnace. Both centrifugal* and axial fans† can be used. To cater for changes in boiler load, the fan output of centrifugal units is adjusted using variable geometry inlet vanes or variable speed. Blade adjustment (in motion) is used to regulate the airflow with axial fans.
Induced draught fans (ID)	These fans are situated at the opposite end of the boiler ducting system to FD fans and handle combustion gases, normally at around 140˚C. The fans are specially designed to cope with the higher gas temperatures and, in some cases, must be able to cope with erosive dust. As for FD fans, the fan output must be adjustable to cater for the variable output of the boiler unit. Because of the lower gas density, ID fans are larger than the FD fans but, in many cases, look similar. Both centrifugal* and axial fans† can be used but, when dust particles are present, axial fan blades require a more elaborate erosion protection system.
Primary air fans (PA)	This type of fan is only found in coal-fired plants, where its main function is to transport powdered coal into the furnace. It draws atmospheric air and supplies it to a heat exchanger, where the air temperature is normally raised to around 30˚C. The hot air then passes through the coal grinding plant, where it picks up the coal dust and transports it to the furnace. Although PA fans are significantly smaller than the FD and ID fans, they still absorb significant power because of the requirement to provide a much higher air pressure. Due to this higher pressure requirement, the duty is more suited to a centrifugal* fan.

Table 4 Types of boiler mechanical draught fans

**See Figure 3. †See Figure 4.*

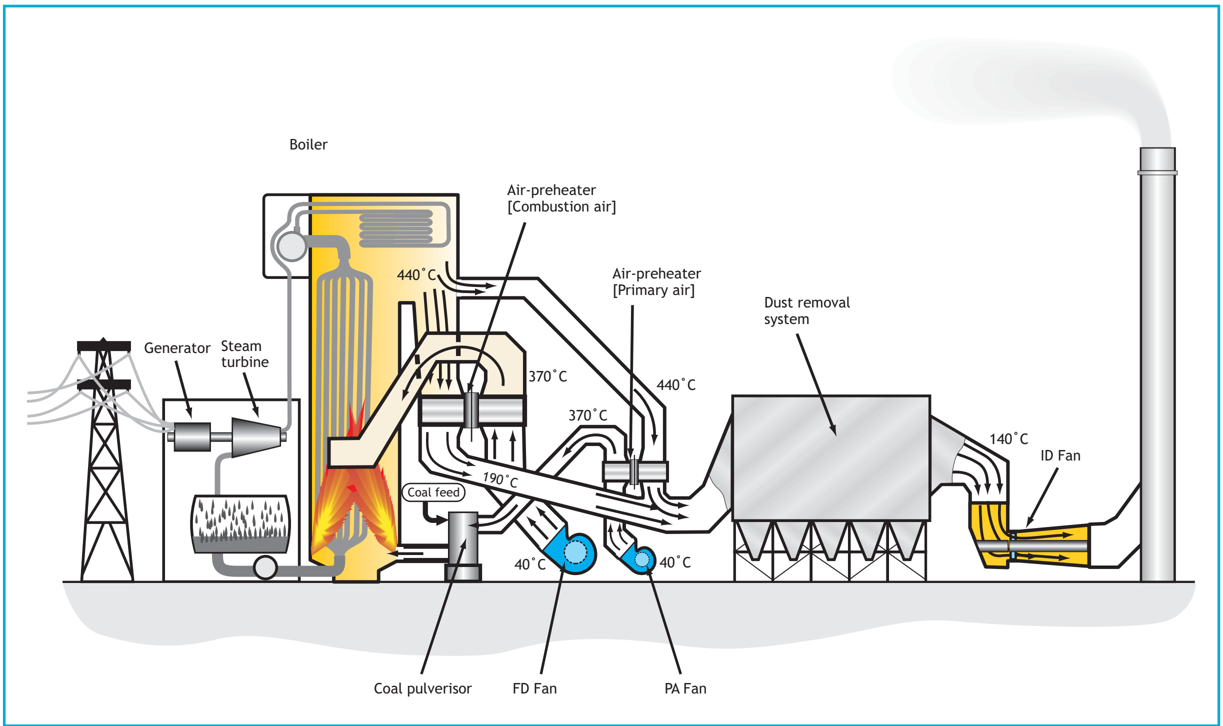


Figure 18 Layout of coal-fired boiler house

4.1.1 Reducing energy consumption

Boiler plant is generally designed to allow significant flexibility in matching the electrical output to that demanded by the supply. As a result, a significant amount of time can be spent at reduced load. Fixed speed fans operated away from their design duty normally run with reduced efficiency; this typically results in a decrease in fan efficiency from over 85% to around 60%.

There are a number of ways of improving fan energy consumption by allowing the unit to operate at high efficiencies even at part-load output. Options for FD and ID centrifugal fans are given below (with the most effective first and the least effective last):

- Variable speed
- Two-speed combined with inlet vane control (this allows part load operation at the lower speed)
- Single speed with variable geometry inlet vane control
- Single speed with close-coupled inlet louvered dampers.

Resistance variable or twin-speed options are unsuitable for PA fans, because they operate against a non-square law system. The options for centrifugal PA fans are therefore reduced to the final two options given above.

Axial fans, which are normally only suitable for FD and ID duties, are usually supplied with a mechanism that allows the simultaneous adjustment of the blade pitch with the fan in motion. This effectively means that the fan impeller geometry can be varied over a wide range to provide an excellent match with the duty requirement. For this reason, variable speed is usually of no real benefit, because the fan can maintain a high efficiency across a large flow envelope while operating at a single speed.

4.2 Dust and fume extraction

There are two options for dust and fume extraction using fans.

- **Local exhaust** reduces potential atmospheric pollution from a mechanical or chemical process, by moving a mass of air across possible escape routes to capture the contaminant as close as possible to its source.
- The **dilution method** reduces the concentration of the contaminant below the danger level, by introducing a larger quantity of clean air and removing a corresponding amount of dirty air from the affected area.

Local exhaust gives more positive control than the dilution method.

Examples of the many different types of extraction system include:
- Wood refuse plants – to keep saws, planers and other machines working
- Fume extract plants – to extract fumes that would be harmful to health if allowed to escape
- Kitchen extract systems – to remove unpleasant odours and steam
- Recovery plant – where mechanical processes such as machining, milling or polishing produce a dust which has a value
- Prevention of atmospheric pollution.

All such systems use ductwork, fans and hoods to capture and transport the contaminants. Depending on the application, they may also incorporate some form of air cleaner or dust collector. The cost of operating and maintaining these systems can be considerable. It is therefore essential to minimise dust/fume production and to ensure efficient capture of the contaminants so that the amount of extract air is minimised. This is especially important where dangerous fumes have to be extracted. Some fumes may act as cumulative poisons, while some mixtures of fine dust particles and air can become explosive and must be avoided.

4.2.1 Types of material extracted

Two main categories of particles are removed using extraction fans:
- Fine dusts, fumes, vapours and smokes, which can generally be dealt with by air movement
- Heavier particles that require specialist precautions and should be caught in their trajectory. Exhaust hoods must be located in the path of the particles.

For both categories, it can be advantageous to use both blowing as well as exhaust openings, in a so-called 'push-pull' system. This can help to reduce factory heating loads by decreasing the number of air changes. The blower air can be cold.

Air can be recirculated into occupied spaces, but only if the dust or fume is non-toxic, the collection efficiency is high and there are no small particles that elude collection. Solid particles are not assumed to affect the flow because they form a very small proportion of the total flow.

4.2.2 Hood design

Refinements in hood design include double-skinned extract hoods, which create a curtain effect, thus reducing the extract volume and hence the power consumed. Such designs tend to cost more and weigh more. Weight is an important consideration as hoods are usually supported from roof trusses. Cleaning is also more difficult with a baffled or double hood.

In some sectors, such as the automotive industry, a monorail system is needed above the production track and it is difficult to fit an extraction hood. Side extraction may be the only possible solution in such cases.

4.2.3 Duct features

When heavier particles such as wood chips are being extracted, duct wall thickness should be increased and bends be offset slightly at their beginning (where possible) to reduce the risk of damage. Damage can lead to leakage into extract ducts with a consequent loss of suction and a possible increase in power.

The inside of ducts should be smooth and care should be taken at gaskets in flanged ductwork, to ensure that there are no lips.

With condensable fumes, low points in duct systems should be fitted with drain points. A drain should be incorporated in the fan casing.

All bends should be of a sufficient diameter to minimise pressure loss. Ducts should generally be not less than 100mm in diameter to prevent clogging, although this size is given as guidance only and should be used with discretion.

Airtightness is another important issue; higher pressure losses mean that in-leakage may be quite large, thus ‘robbing’ the furthest sections of the system. If dampers must be used, then the slide type (coming from the top of the duct) is recommended so that no dust build-up occurs.

Sweep-up points should be self-closing and airtight. It is not normal to allow for a large quantity of air flowing through them, as they are open only for short periods.

Electrical continuity should be arranged across flanged sections, otherwise the build-up of static electricity would lead to sparking across gaskets.

5 Energy savings checklist

This section contains a comprehensive energy saving checklist. It gives a series of questions to help identify potential improvements, together with suggestions for action and typical potential energy savings (in percentage terms).

The checklist of measures in Table 5 should be consulted after an initial performance test to determine the actual flow rate, pressure and power absorbed by the installed/proposed fan.

Area	Check	Possible improvements	Typical savings	See Section
Application	Is the system doing useful work?	Significant energy savings can be achieved by stopping the fan when the ventilation is not required.	10-50%	1
Design	Has the fan been sited to reduce system resistance?	Poor design can mean the ductwork has unnecessary bends and fittings, or even that the length of ductwork is excessive. Careful consideration of the fan location at the design stage can lead to significant energy	5-30%	3.2
Performance	Can a control method be used to match the fan speed to demand?	Many control systems are available. By monitoring the demand, the airflow rate can be adjusted to meet the demand, e.g. using a variable speed drive (VSD). For larger axial fans, adjusting the pitch of the blades is a common method of adjusting the airflow. Savings can be as high as 30%. **Note:** Where there is no need to adjust the airflow rate, installing a VSD could increase energy consumption by 5%.	-5-30%	3.5
Fan	If it is a centrifugal fan, is it running in wrong direction or is a wrong-handed impeller fitted?	Change the fan direction or replace the impeller.	Depends on fan type	3.5
	If it is a centrifugal fan, is it handling an incorrect volume of air?	Change the impeller to reduce energy consumption.	Depends on fan type	3.5
	Is a complete change of fan justified to obtain a significant improvement in fan and system efficiency?	Significant savings can by achieved by selecting efficient fans that are sized as accurately as possible to work at the correct flow near their point of most efficient operation.	5-30%	3.2
	Is the swirl at the inlet the opposite direction to the fan rotation?	Straighten out the flow in the inlet with fixed vanes.	5-15%	3.1
	Are turning vanes fitted where there is a duct bend close to the inlet?	Install vanes if not fitted.	5-15%	3.1
	Is a transition piece fitted where the duct size reduces?	Install a transition piece if not fitted.	5-10%	3.1
	Are flexible connections fitted correctly with no offset or slack?	Carry out a visual inspection to ensure correct connection.	Up to 30% on low pressure axial fans	3.1

Table 5 *Checklist of energy saving measures in fans and fan systems*

Area	Check	Possible improvements	Typical savings	See Section
Fan outlet	If there are bends in the ductwork close to the outlet, are these radius bends with splitters?	It is generally good practice not to have bends close to the outlet.	Depends on orientation	3.1
	If the fans are an axial or propeller type, are guide vanes fitted to provide energy recovery?	Guide vanes should be considered when the pressure is above 750 pascals.	Depends on pitch angle	3.1
	Is the swirl at the inlet in the opposite direction to the fan rotation?	Motor overload is possible. Consider installing upstream straightening vanes.	0-15%	3.2
Motor	Is the motor oversized?	Losses are often caused by too large a safety margin being introduced during the design and installation stages, resulting in the specification of too large a motor. Modern motors give good performance from 50-100% of rated load, making selection a little easier; however, selection of the right motor remains important.	5-10%	3.2
	Is a three-phase motor operating on all three phases?	Check for faulty wiring and fuses.	0-15%	3.2
	Is an AC motor running below its normal speed due to a winding or starting fault?	Check the connection diagram with the motor.	0-10%	3.2
	Is a higher efficiency motor (HEM) being used?	Apart from very low duty applications, it is always worth fitting HEMs that are classified as Eff 1 or that appear on the Energy Technology List (see www.eca.gov.uk).	2 - 5%	3.2
	Is a higher efficiency motor (HEM) being used?	Apart from very low duty applications, it is always worth fitting HEMs that are classified as Eff 1 or that appear on the Energy Technology List (see www.eca.gov.uk).	2 - 5%	3.2
Ducting	Is the ducting tubular with a large cross-sectional area?	Installing tubular ducting instead of standard rectangular ducting and ensuring that the cross-sectional area is as large as possible will produce a low velocity system with a low pressure drop, thus maximising efficiency.	7%	3.1
	When balancing using dampers, has the pressure drop been minimised?	Good design should ensure that all legs have equal pressure losses. After installation, a ventilation system must be balanced to ensure that all areas receive the ventilation required. Care should be taken when selecting dampers for balancing to minimise the pressure drop.	7%	3.1
Site performance	Have checks been carried out throughout the site on airflow rate, pressure and absorbed power?	Possible actions identified by a site test are change of fan speed, new fan drive, change of fan motor (e.g. to a higher efficiency type or a different power rating), change of fan size and capacity control to meet varying load demand.	7%	3.5

Table 5 *Checklist of energy saving measures in fans and fan systems continued*

Appendix A – Glossary

Adjustable pitch The mechanism in general purpose fans that allows the pitch angle of the blades to be adjusted to exactly match the air volume flow required.

Air velocity The velocity of an air stream is its rate of motion, expressed in metres/second. The velocity at a plane (V_x) is the average velocity throughout the entire area of the plane.

Ambient temperature The dry-bulb temperature (t_d) is the air temperature measured by a dry temperature sensor. The temperatures relating to air density are usually referenced to the fan inlet.

The wet-bulb temperature (t_w) is the temperature measured by a temperature sensor covered by a water-moistened wick and exposed to the air in motion.

Wet-bulb depression is the difference between dry and wet bulb temperatures (t_d – t_w) at the same location.

Belt tube Where a fan is mounted in the air passage way and the motor is external to the passageway, the belt tube contains the drive belt between the motor and the fan.

Density Mass of air per unit volume (1.2kg/m^3 at 16°C and atmospheric pressure, e.g. 100kPa).

Fan A fan is a power driven machine that moves a continuous volume of air by converting rotational mechanical energy to an increase in the total pressure of the moving air. The conversion is accomplished by changing the momentum of the fluid.

Fan characteristic The curve which describes the fixed relationship between pressure rise and volume flow for a specific fan.

Fan components *Impeller* The rotating blades on the fan shaft that exert force on the air and thus maintain the airflow at increased pressure.

Casing The shaped casing surrounding the impeller that provides a barrier between the inlet and outlet sides of the fan.

Motor The means of rotating the fan.

Guide vanes Radial vanes mounted at the inlet or outlet to a fan to improve the airflow and hence the fan efficiency.

Life-cycle cost The total cost of ownership of an item taking into account all the costs of acquisition, personnel training, operation, maintenance, modification and disposal.

Power *Air power* is the energy imparted by the fan to the air by increasing its pressure from that at the inlet to that at the outlet, and is the product of the inlet volume flow and the fan pressure.

Fan shaft power is the mechanical power supplied to the fan shaft.

Impeller power is the mechanical power supplied to the fan impeller.

Motor output power is the shaft power output of the motor.

Pressure *Static pressure* is the portion of the air pressure due to the degree of compression. If expressed as gauge pressure, it may be negative or positive.

Velocity pressure exists due to the rate of motion. It is always positive.

Total pressure is the air pressure due to the degree of compression and rate of motion. It is the algebraic sum of the static and velocity pressures at a point. If the airis at rest, the total pressure equals the static pressure.

Fan pressure is the difference between the fan inlet pressure and the fan outlet pressure.

Specific fan power The sum of the design total circuit watts (including all losses through switchgear and controls such as inverters) of all fans that supply air and exhaust it back to outdoors (i.e. the sum of supply and extract fans) divided by the design ventilation rate through the building.

Variable speed drives An electronic device that converts the AC mains supply to DC using a rectifier and then produces a variable frequency, variable voltage at the motor terminals to enable an induction motor to be run efficiently at different speeds.

Volume flow The volume flow rate at a plane (Q_x) is the rate of flow, expressed in litres/second, and is the product of the average velocity flow at the plane and the area of the plane.

Appendix B – Life-cycle costing

The accepted method of calculating the life-cycle cost of a fan installation is to convert to a present day value:

- Investment cost
- Annual energy and power costs during the working life of the fan and drive motor
- Disposal costs
- Assumed future maintenance costs
- Assumed disposal or environmental costs.

Life-cycle cost (LCC) can be defined as:

LCC = Investment + Energy consumed + Maintenance costs + Disposal costs

Investment

This consists of the capital cost of the fan and its ancillaries including the driving motor, transmission (e.g. vee belt drive) and control gear (starters, circuit fuses, inverters, etc.).

Dampers (variable inlet vanes, side control for inlet boxes, etc.) should also be included where adjacent to the fan and special foundations, together with installation costs and commissioning.

Capital costs should also include special plant rooms and their associated building costs.

Energy

This is calculated from the flow rate and fan pressure, then brought to present day values and integrated over its working life. The input power is included in the equation.

$$W \text{ (power input) watts} = \frac{Q \times p_F}{\rho_f \times \rho_m \times \rho_t \times \rho_c}$$

where: Q = air or gas flow rate in m^3/second

p_F = fan (total) pressure in kPa

ρ_f = fan (total) efficiency expressed as a decimal

ρ_m = motor efficiency expressed as a decimal

ρ_t = transmission efficiency expressed as a decimal

ρ_c = controls efficiency expressed as a decimal.

In many systems (e.g. variable air volume, mechanical draught), the flow rate varies continuously. To calculate the total kWh, it is important to know the percentage of time at which the plant operates at its design maximum and the general pattern of output versus time.

Maintenance

This can be categorised as routine or incident related.

Routine tasks that need to be carried out at specified intervals include:

- Lubrication of fan and/or motor bearings
- Cleaning of impellers
- Tensioning vee belts.

Bearing manufacturers know the amounts of oil or grease required for effective lubrication in terms of both the charge (quantity) and frequency (time interval). They can also assess the life of bearings under specified loads and speeds.

Example calculation

The following example is based on simple payback and looks at the cost of each element without making an adjustment for the changing value of money over time.

The example demonstrates that the purchase of a fan based only on its initial cost (Fan B) can result in a significant increase in total costs over the life-cycle of the project. In this case, the difference in whole life value between the two fans amounts to some 30% of the whole life value of Fan A.

Fan	Capital cost	Expected service life (years)	Energy cost*	Maintenance cost*	Disposal cost	Life-cycle cost
A	£5,700	10	£4,600	£2,700	£870	£13,870
B	£3,200	5	£10,300	£3,400	£750	£21,600

**Over ten years*

Appendix C – Sources of further information

Useful contacts

Action Energy
Helpline: 0800 58 57 94
www.actionenergy.org.uk

Fan Manufacturers Association (FMA)
The Federation of Environmental Trade Associations
Henley Road, Medmenham, Marlow, Buckinghamshire SL7 2ER
Tel: 01491 578674
E-mail: info@feta.co.uk
www.feta.co.uk/fma

Air Movement & Control Association International, Inc. (AMCA)
30 West University Drive, Arlington Heights, IL 60004-1893, USA
Tel: +1 404 847/394-0150
E-mail: amca@amca.org
www.amca.org

British Standards Institution (BSI)
389 Chiswick High Road, London W4 4AL
Tel: 020 8996 9000
E-mail: cservices@bsi-global.com
www.bsi-global.com

BSI publishes all British Standards covering the manufacture, installation and testing of fans and components (a BS number followed by EN indicates that the standard is also a European one).

Building Services Research and Information Association (BSRIA)
Old Bracknell Lane West, Bracknell, Berkshire RG12 7AH
Tel: 01344 426511
www.bsria.co.uk

Chartered Institution of Building Services Engineers (CIBSE)
Delta House, 222 Balham High Road, London SW12 9BS
Tel: 020 8675 5211
www.cibse.org

Health and Safety Executive (HSE)
HSE Infoline
Tel: 0870 154 5500
www.hse.gov.uk
HSE publications are available from:
HSE Books, PO Box 1999, Sudbury, Suffolk CO10 6FS
Tel: 01787 881165
www.hsebooks.co.uk

Useful publications

- **Building Regulations 2000**: Approved Document L2 – Conservation of fuel and power in buildings other than dwellings. 2002 edition. ISBN 0117536105. Can either be downloaded from www.odpm.gov.uk or purchased from The Stationery Office (Tel: 0870 600 5522; www.thestationeryoffice.com).

- **CIBSE guides** – a series of substantial reference guides is available, with more in preparation. See Appendix C for contact details.

- **Eurovent Certification Company SCRL** – a series of publications from the EUROVENT certification programme, which utilises European and International standards to create a common set of criteria for rating fans and other products. For more information, see from www.eurovent-certification.com.

- **Market Study for Improving Energy Efficiency for Fans**. Peter Radgen (editor). ISBN 3816761372. Fraunhofer IRB Verlag (2002)

The Fan Manufacturers Association (FMA) offers a series of publications:

- **Fan Application Guide** – covers the basic knowledge required, together with the pitfalls to avoid, in order for an installation to do what it was designed for.
- **Fan and Ductwork Installation Guide** – reports measurements of the effects of commonly used ductwork fittings on fan performance.
- **Guide to Fan Noise and Vibration** – provides information on noise and vibration issues relating to fans and fan installations. The information ranges from fundamental definitions to practical advice.
- **Fan Installation Effects** – a guide to installed performance (Guidance Note 1)
- **Fan Installation Effects** – a guide to installed fan acoustics (Guidance Note 2)

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Tel 0800 58 57 94

www.actionenergy.org.uk

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